N69-15680
nasa CR-99121

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EVALUATION PROGRAM
for
SECONDARY SPACECRAFT CELLS

GENERAL PERFORMANCE TEST
OF
GENERAL ELECTRIC COMPANY
6.0 AMPERE-HOUR
NICKEL-CADMIUM CELLS

prepared for
GODDARD SPACE FLIGHT CENTER
CONTRACT W11,252B

QUALITY EVALUATION LABORATORY

NAD CRANE, INDIANA

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QUALITY EVALUATION LABORATORY
UNITED STATES NAVAL AMMUNITION DEPOT
CRANE, INDIANA

EVALUATION PROGRAM
FOR
SECONDARY SPACECRAFT CELLS

GENERAL PERFORMANCE TEST
OF
GENERAL ELECTRIC 6.0 AMPERE-HOUR
NICKEL-CADMIUM SECONDARY
SPACECRAFT CELLS

QE/C 68-926 22 NOVEMBER 1968

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By direction

Enclosure (1)

REPORT BRIEF
RESULTS OF GENERAL PERFORMANCE TESTS OF 6.0 AMPERE-HOUR SEALED NICKEL-CADMIUM CELLS MANUFACTURED BY GENERAL ELECTRIC COMPANY

Ref: (a) National Aeronautics and Space Administration Purchase Order Number W11,252B
(b) NASA ltr BRA/VBK/pad of 25 September 1961 w/BUWEPS first end FQ-1:WSK of 2 October 1961 to CO NAD Crane
(c) NASA memo ERS of 27 June 1967 to NAD Crane
(d) Grumman Aircraft Engineering Corporation OAO Project memorandum 64-108 of 30 November 1964

I. TEST ASSIGNMENT BRIEF

A. In compliance with references (a) and (b), evaluation of sealed nickel-cadmium cells was begun according to the program outline of reference (c). Environmental tests were conducted according to reference (d).

B. The object of this evaluation program is to gather performance information concerning sealed nickel-cadmium cells designed for use in spacecraft. The performance characteristics and limitations under various electrical and environmental conditions will be of interest to power system designers and users.

C. Five cells were purchased by National Aeronautics and Space Administration (NASA) from General Electric Company, Gainesville, Florida. These cells are rated at 6.0 ampere-hours by the manufacturer.

II. SUMMARY OF RESULTS

A. The cells were capable of withstanding the vibration, mechanical shock and acceleration requirements.

B. Charge and Discharge Voltage Characteristics:

1. When charged at various rates and temperatures:

a. At -20° C the end of charge cell voltages increased from 1.46 to 1.83 volts as the rate of recharge increased from c/40 to 2c. The cell temperatures did not vary more than a few degrees from the ambient. The maximum capacity delivered was obtained following the c/20 charge rate.

b. At 0° C the end of charge cell voltages increased from 1.42 to 1.72 volts as the rate of recharge increased from c/40 to 2c. The cell temperatures did not vary more than a few degrees from the ambient. The maximum capacity delivered was obtained following the c/2 charge rate.

c. At 20° C the end of charge cell voltages increased from 1.41 to 1.64 volts as the rate of recharge increased from c/40 to 2c. The cell temperatures did not vary more than a few degrees from the ambient. The maximum capacity delivered was obtained following the c/5 charge rate.

d. At 40° C the end of charge cell voltages increased from 1.36 to 1.59 volts as the rate of recharge increased from c/40 to 2c. The cell temperatures did not vary more than a few degrees from the ambient. The maximum capacity was obtained following the c/1 charge rate.

2. When discharged at various rates and temperatures:

a. At -20° C the difference between the cell temperatures and the ambient temperature was insignificant for discharge rates from c/40 to c/5 but increased with increase of rates to 2c. The maximum capacity delivered was obtained at the c/20 discharge rate.

b. At 0° C the difference between the cell temperatures and the ambient temperature was insignificant for discharge rates from c/40 to c/5 but increased with increase of rates to 2c. The maximum capacity delivered was obtained at the c/20 discharge rate.

c. At 20° C the difference between the cell temperatures and the ambient temperature was insignificant for discharge rates from c/40 to c/5 but increased with increase of rates to 2c. The maximum capacity delivered was obtained at the 2c discharge rate.

d. At 40° C the difference between the cell temperatures and the ambient temperature was insignificant for discharge rates from c/40 to c/5 but increased with increase of rates to 2c. The maximum capacity delivered was obtained at the c/10 discharge rate.

C. Overcharge Characteristics:

1. The lower the ambient temperature of the cells, the higher were the stabilized cell voltages during overcharge. This was true at each of the seven overcharge rates. The difference between the cell temperature and that of its respective ambient for each of the four cells on the overcharge test showed a decrease in temperature difference with an increase in ambient temperature.

RESULTS OF GENERAL PERFORMANCE TESTS OF 6.0 AMPERE-HOUR SEALED NICKEL-CADMIUM CELLS MANUFACTURED BY GENERAL ELECTRIC COMPANY

I. INTRODUCTION

A. The General Performance Tests on five cells were begun on 29 November 1967 and completed on 7 March 1968.

II. TEST CONDITIONS

A. These tests were performed at existing relative humidity and atmospheric pressure and at four specific temperatures. The tests and test temperatures were as follows:

1. Random vibration at room ambient temperature.

2. Sinusoidal vibration at room ambient temperature.

3. Mechanical shock at room ambient temperature.

4. Acceleration at room ambient temperature.

5. Charge and discharge voltage characteristics at various specified charge rates at -20° C, 0° C, 20° C and 40° C.

6. Charge and discharge voltage characteristics at various specified discharge rates at -20° C, 0° C, 20° C and 40° C.

7. Overcharge characteristics at -20° C, 0° C, 20° C and 40° C.

B. All charging was by constant current to 100 percent of the manufacturer's rated capacity, c, except that at room ambient which was done at the c/10 rate for 16 hours. All discharges were by constant current to 0.0 volt.

III. CELL IDENTIFICATION AND DESCRIPTION

A. The five General Electric 6.0 ah nickel-cadmium cells, supplied by Goddard Space Flight Center, were identified by the manufacturer's serial numbers 11-13, 11-17, 11-44, 11-45 and 11-46.

B. The cell containers and covers are made of stainless steel. Both terminals of each cell are insulated from the cell cover by ceramic seals and protrude through the cover as solder type terminals.

IV. TEST PROCEDURES AND RESULTS

A. Random Vibration Test:

1. Each cell was charged at the c/10 rate for 16 hours, following which they were individually mounted in a rigid test fixture attached to the table of an M. B. Electronics Model C-10 vibrator. The amplitude or acceleration was monitored on the test fixture near the mounting points.

2. Each cell was subjected to gaussian random vibration applied to each axis for 8 minutes with the "g-peaks" clipped at three times the root-mean-square acceleration as specified in the schedule. The vibration was applied successively to the Z, X and Y axes. With a cell installed, the control accelerometer response was equalized with peak-notch filterization such that the specified power spectral density (PSD) values were within ± 3 db throughout the frequency band.

RANDOM VIBRATION SCHEDULE

Longitudinal Axis		Lateral Axes	
Frequency Range Hz	PSD Level g^2/Hz	Frequency Range Hz	PSD Level g^2/Hz
15-70	0.030	15-70	0.030
70-400	0.0225	70-150	0.0225
400-800	0.045	150-2000	0.030
800-2000	0.030		

3. During the applied vibration, the cells were discharged at the c/2 rate. The discharge current and the terminal voltage were monitored for evidence of cell malfunction during the applied vibration. After the vibration test, the cells were visually examined for evidence of mechanical damage.

4. There was no evidence of damage or malfunction of the five cells due to the random vibration test.

B. Sinusoidal Vibration Test:

1. Each cell was prepared as described in paragraph IV.A.1.

2. Each cell was subjected to sinusoidal vibration at a sweep rate of one octave per minute with two exposures. The

vibration was applied successively to the Z, X and Y axes as specified in the following schedule.

SINUSOIDAL SWEEP SCHEDULE

Frequency Range Hz	Level
5-8	0.5" D.A.
9-14	Linear decrease to 0.2" D.A.
15-54	0.2" D.A.
55-2000	30 g's

3. During the applied vibration, the cells were discharged at the c/5 rate. The discharge current and the terminal voltage were monitored for evidence of cell malfunction during the applied vibration. After the vibration test, the cells were visually examined for evidence of mechanical damage.

4. There was no evidence of damage or malfunction of the five cells due to the sinusoidal vibration.

C. Mechanical Shock Test:

1. Each cell was charged at the c/10 rate for 16 hours. The cells were then individually mounted in a rigid test fixture attached to the Barry Type 16805 Shock Machine.

2. Each cell was subjected to two, half-sine wave shock pulses of 30 g ± 10 percent amplitude in the Z, X and Y axes. The time duration of the two pulses were 6 and 12 milliseconds ± 10 percent, respectively.

3. During the shock test, the cells were discharged at the c/2 rate. The discharge current and the terminal voltage were monitored during the shock test for evidence of malfunction of any cells.

4. At the conclusion of the test, the cells were examined for evidence of mechanical damage.

5. There was no evidence of damage or malfunction of the five cells due to the mechanical shock tests.

D. Acceleration Test:

1. Each cell was charged at the c/10 rate for 16 hours. The cells were then individually mounted in a rigid test fixture attached to the Genisco Model C-159 Centrifuge.

2. Each cell was subjected for 4.5 minutes per axis to acceleration at the g-levels specified below.

G-Level	Axis
11.3	+X
2.3	±Y, ±Z
3.0	-X

3. During the acceleration tests, the cells were discharged at the c/2 rate. The discharge current and the terminal voltage were monitored for evidence of cell malfunction during the acceleration test periods.

4. At the conclusion of the tests, the cells were examined for mechanical damage.

5. There was no evidence of damage or malfunction of the five cells due to the acceleration tests.

E. Cell Preparation:

1. The five cells were prepared in the following manner for the charge and discharge voltage characteristics test and the overcharge characteristics test.

a. Each cell was restrained between two 1/4-inch steel plates.

b. A thermocouple was attached between the center of one outside surface of the cell and the adjacent plate.

F. Charge and Discharge Voltage Characteristics:

1. At specified charge rates:

a. The cells were discharged at the c/2 rate at room temperature. Each cell, in turn, was removed from the circuit when its voltage reached 0.0 volt, and was then shorted for a period of 30 to 60 minutes. The cells were then recharged at the c/10 rate for 16 hours. Following a 15-minute open circuit stand, the cells were given a capacity test discharge at room temperature at the c/2 rate to 0.0 volt as above, and again shorted for a period of 30 to 60 minutes.

b. The cells were then placed in a controlled temperature chamber and allowed to stabilize at -20° C.

c. The cells were then recharged at the c/40 rate to 100 percent of the manufacturer's rated capacity. Following a 15-minute stand, the cells were discharged at the c/2 rate to 0.0 volt each and shorted for a period of 30 to 60 minutes.

d. Paragraph IV.F.1.c. was repeated for c/20, c/10, c/5, c/2, c/1 and 2c charge rates.

e. Upon completion of the above sequence at -20° C with the seven charge rates, the tests of paragraphs IV.F.1.c. and IV.F.1.d. were repeated at 0° C, 20° C and 40° C.

f. Test Results:

(1) The test results are shown graphically in Figures 1 through 7. Because of the large volume of data, only average values of the recorded data are plotted. More detailed data is available upon request. The average values of cell voltages and temperature differences (between cell skin and ambient temperatures) taken throughout the charge and discharge periods for each fixed charge rate at each of the four ambient temperatures were plotted against the corresponding percentage of the manufacturer's rated capacity. These graphs show the effects of each of the four ambient temperatures on the cell voltage, the cell temperature and the ampere-hour efficiency of the cells discharged at a fixed rate of c/2 following a 100 percent charge at each of the seven charge rates.

(2) The end of charge voltage increased with decreasing temperature at all rates. As charge rates were increased from c/40 to 2c, the end of charge voltage increased from 1.46 to 1.87 volts at -20° C, from 1.42 to 1.72 volts at 0° C, from 1.41 to 1.64 volts at 20° C, and from 1.36 to 1.59 volts at 40° C.

(3) Figure 8 is a summary of the capacities delivered following each of the seven charge rates to 100 percent of the manufacturer's rated capacity. Capacities are plotted as a percentage of the manufacturer's rated capacity. This figure shows the maximum capacity delivered following each charge rate at each ambient temperature. The charge rate that resulted in the maximum delivered capacity at -20° C, 0° C, 20° C and 40° C was c/20, c/2, c/5 and c/1, respectively.

These rates were used at their respective temperatures to charge the cells in the next tests.

2. At specified discharge rates:

a. Following the above tests, the cells were allowed to stabilize at room ambient. The cells were then recharged at the c/10 rate for 16 hours. Following a 15-minute stand, the cells were given a capacity discharge at c/2. Each cell, in turn, was removed from the circuit when its voltage reached 0.0 volt and was then shorted for a period of 30 to 60 minutes.

b. The cells were then allowed to stabilize at -20° C.

c. The cells were charged at the c/20 rate (determined in paragraphs IV.F.1.c. through IV.F.1.e. to give maximum capacity) to 100 percent of the manufacturer's rated capacity. Following a 15-minute stand, each cell was discharged at the c/40 rate to 0.0 volt and then shorted for a period of 30 to 60 minutes.

d. Paragraph IV.F.2.c. was repeated for each of the c/20, c/10, c/5, c/2, c/1 and 2c discharge rates.

e. Upon completion of the above sequence with the seven discharge rates, the tests of paragraphs IV.F.2.c. and IV.F.2.d. were repeated at 0° C with a c/2 charge rate, at 20° C with a c/5 charge rate and at 40° C with a c/1 charge rate.

f. Test Results:

(1) The results are shown graphically in Figures 9 through 15. The average values of cell voltages and temperature differences (between cell skin and ambient temperatures) taken throughout the discharge periods for each fixed discharge rate at each of the four ambient temperatures were plotted against the corresponding percentage of the manufacturer's rated capacity. These graphs show the effects of each of the four ambient temperatures on the cell voltage, the cell temperature, and the ampere-hour efficiency of the cells discharged at each of the seven fixed discharge rates following the charge previously determined to be the most efficient at each of the four temperatures.

(2) The difference between the cell temperature and the ambient temperature was insignificant for the discharge rates from c/40 to c/5 but increased with increase of rates to 2c at all four ambient temperatures.

(3) Figure 16 is a summary of the capacities delivered at the seven discharge rates. Capacities are plotted as a percentage

of the manufacturer's rated capacity. It also shows the maximum capacity delivered at each ambient temperature. The discharge rate that delivered the maximum capacity at each of the four ambient temperatures was c/20 at -20° C, c/20 at 0° C, 2c at 20° C, and c/10 at 40° C.

G. Overcharge Characteristics:

1. Upon completion of the charge and discharge voltage characteristics tests, the discharged cells were allowed to stabilize at room temperature. The cells were then recharged at the c/10 rate for 16 hours. Following a 15-minute stand, each cell was given a capacity discharge at the c/2 rate to 0.0 volt and then shorted for 30 to 60 minutes.

2. Four cells were then allowed to stabilize, one in each of the four ambient test temperatures (-20° C, 0° C, 20° C and 40° C). The fifth cell was kept as a spare in the event of a catastrophic failure.

3. The four cells at their respective temperatures were then subjected to the overcharge sequence listed below:

a. Charge at c/10 for 16 hours; wait 1 hour.

b. Charge at c/40 until the cell voltage stabilizes.

c. Charge at c/20 unitl the cell voltage stabilizes.

d. Charge at c/10 until the cell voltage stabilizes.

e. Charge at c/5 until the cell voltage stabilizes.

f. Charge at c/2 until the cell voltage stabilizes.

g. Charge at c/1 until the cell voltage stabilizes.

h. Charge at 2c until the cell voltage stabilizes.

4. All charging was at constant current with no voltage limit.

5. A drop in voltage of 0.05 volt or more from the highest value observed, or temperatures above 77° C, terminated the tests at the particular ambient temperature.

6. The results are shown graphically in Figure 17 as a plot of the cell voltage and the difference between the cell temperature and the ambient temperature versus the log of the charging current.

7. The voltage at which each cell stabilized increased with increasing charge rate but decreased with increasing ambient temperature. The cell voltage dropped more than 0.05 volt during charge at c/10 at -20° C, and during charge at 2c at 20° C, terminating both tests.

8. The difference between the cell temperature and the ambient temperature increased as the charge rate increased at all four test temperatures. The cell tested at 40° C did not reach a stabilization voltage at the 2c rate before it reached 77° C and was therefore discontinued.

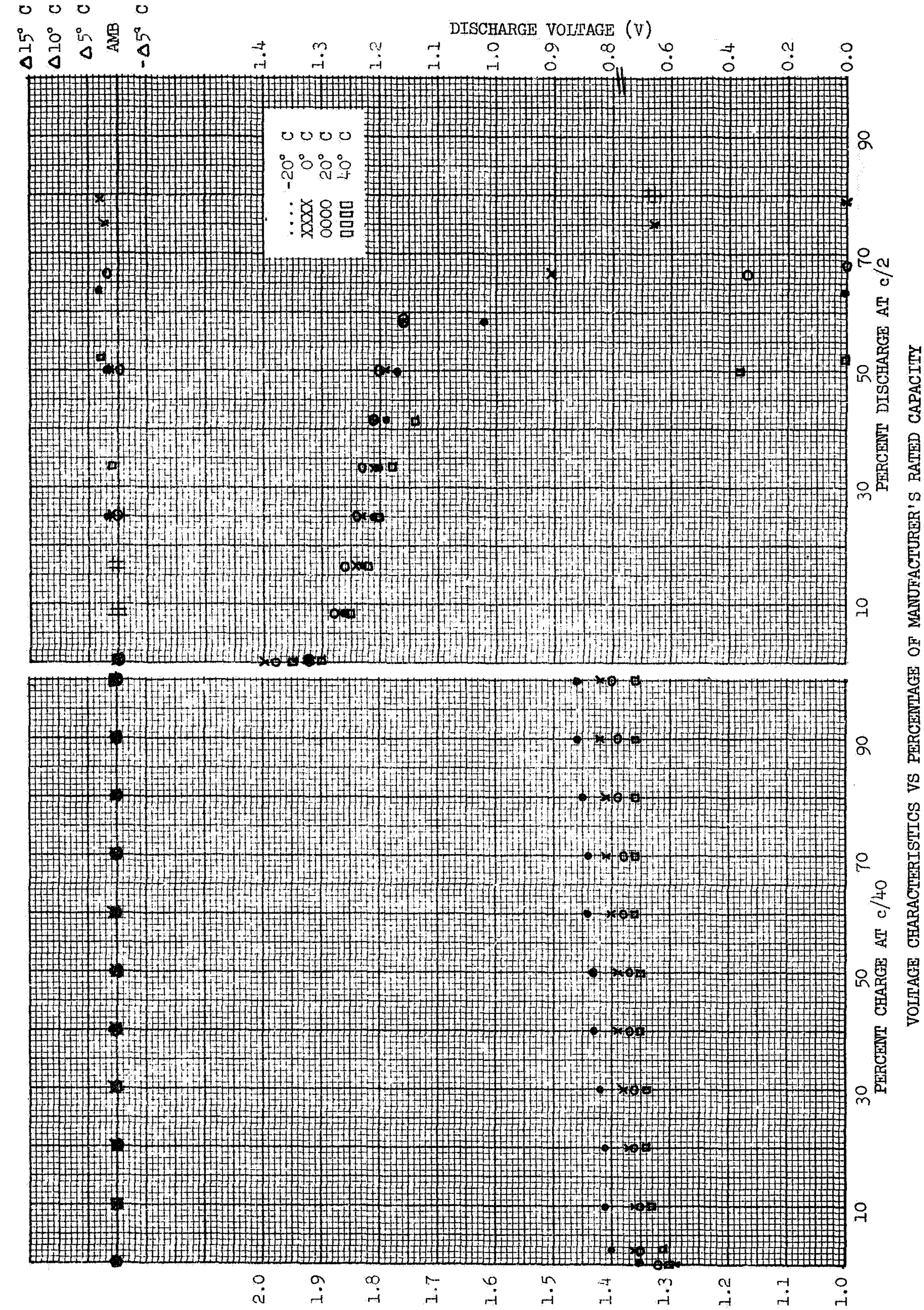

VOLTAGE CHARACTERISTICS VS PERCENTAGE OF MANUFACTURER'S RATED CAPACITY
DISCHARGE VOLTAGE (V)
CHARGE VOLTAGE (V)
PERCENT CHARGE AT c/40
PERCENT DISCHARGE AT c/2
..... -20° C
XXXX 0° C
0000 20° C
□□□□ 40° C
Δ15° C
Δ10° C
Δ5° C
AMB
-Δ5° C

FIGURE 1

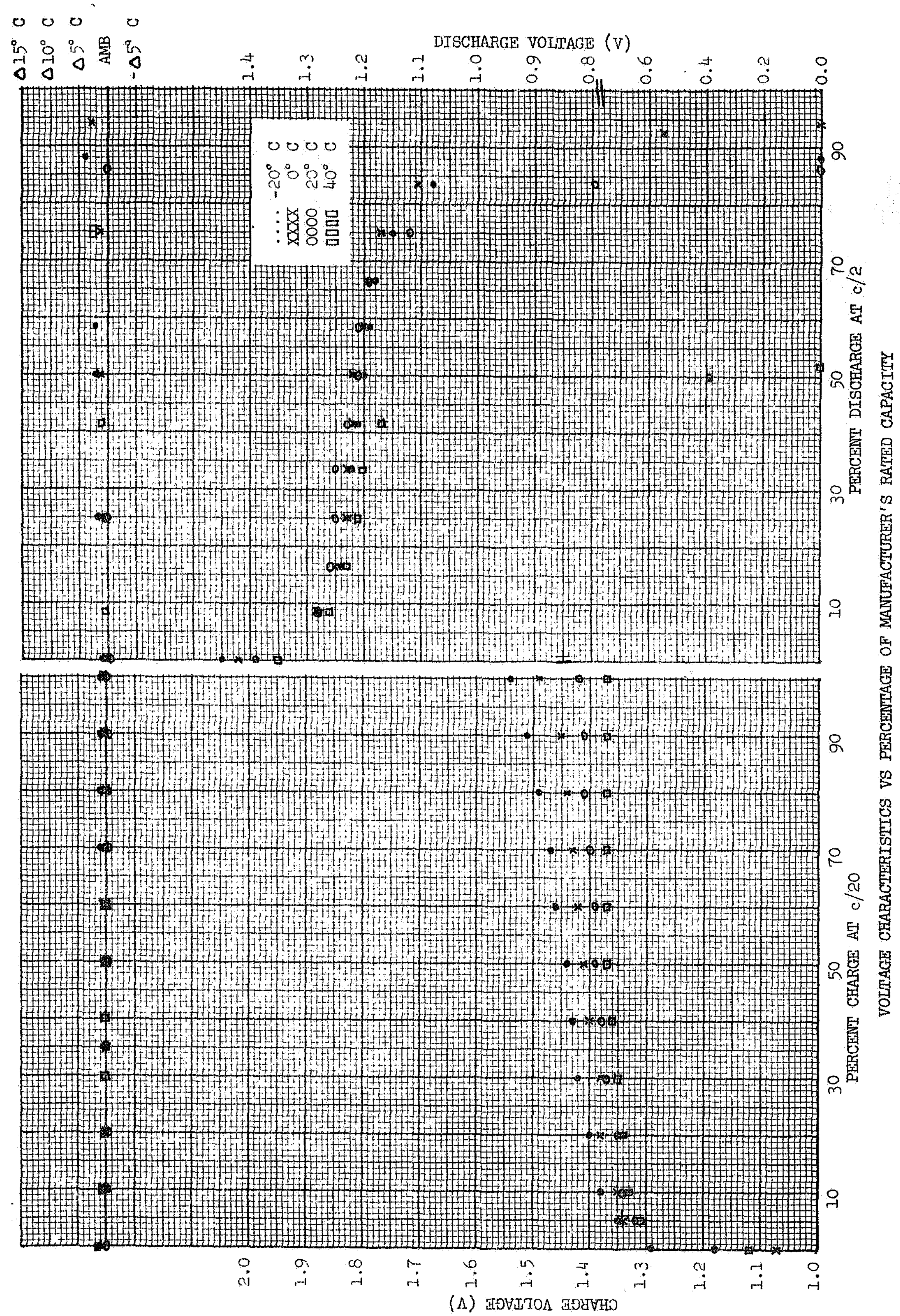

VOLTAGE CHARACTERISTICS VS PERCENTAGE OF MANUFACTURER'S RATED CAPACITY
DISCHARGE VOLTAGE (V)
PERCENT DISCHARGE AT c/2
PERCENT CHARGE AT c/20
CHARGE VOLTAGE (V)
Δ15° C
Δ10° C
Δ5° C
AMB
-Δ5° C
.... -20° C
XXXX 0° C
0000 20° C
▯▯▯▯ 40° C

FIGURE 2

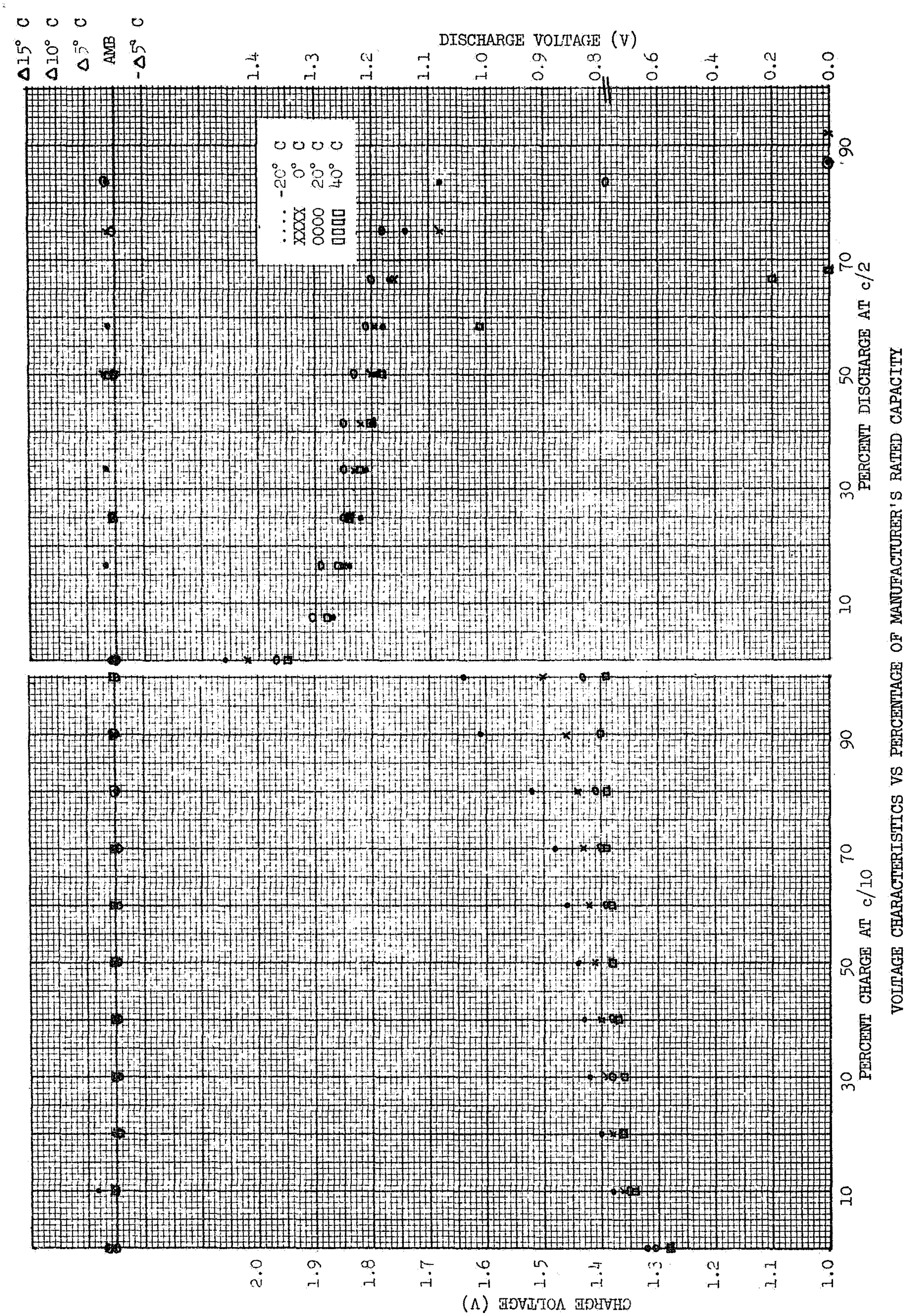

VOLTAGE CHARACTERISTICS VS PERCENTAGE OF MANUFACTURER'S RATED CAPACITY
DISCHARGE VOLTAGE (V)
CHARGE VOLTAGE (V)
PERCENT CHARGE AT c/10
PERCENT DISCHARGE AT c/2
Δ15° C
Δ10° C
Δ5° C
AMB
-Δ5° C
.... -20° C
XXXX 0° C
OOOO 20° C
□□□□ 40° C

FIGURE 3

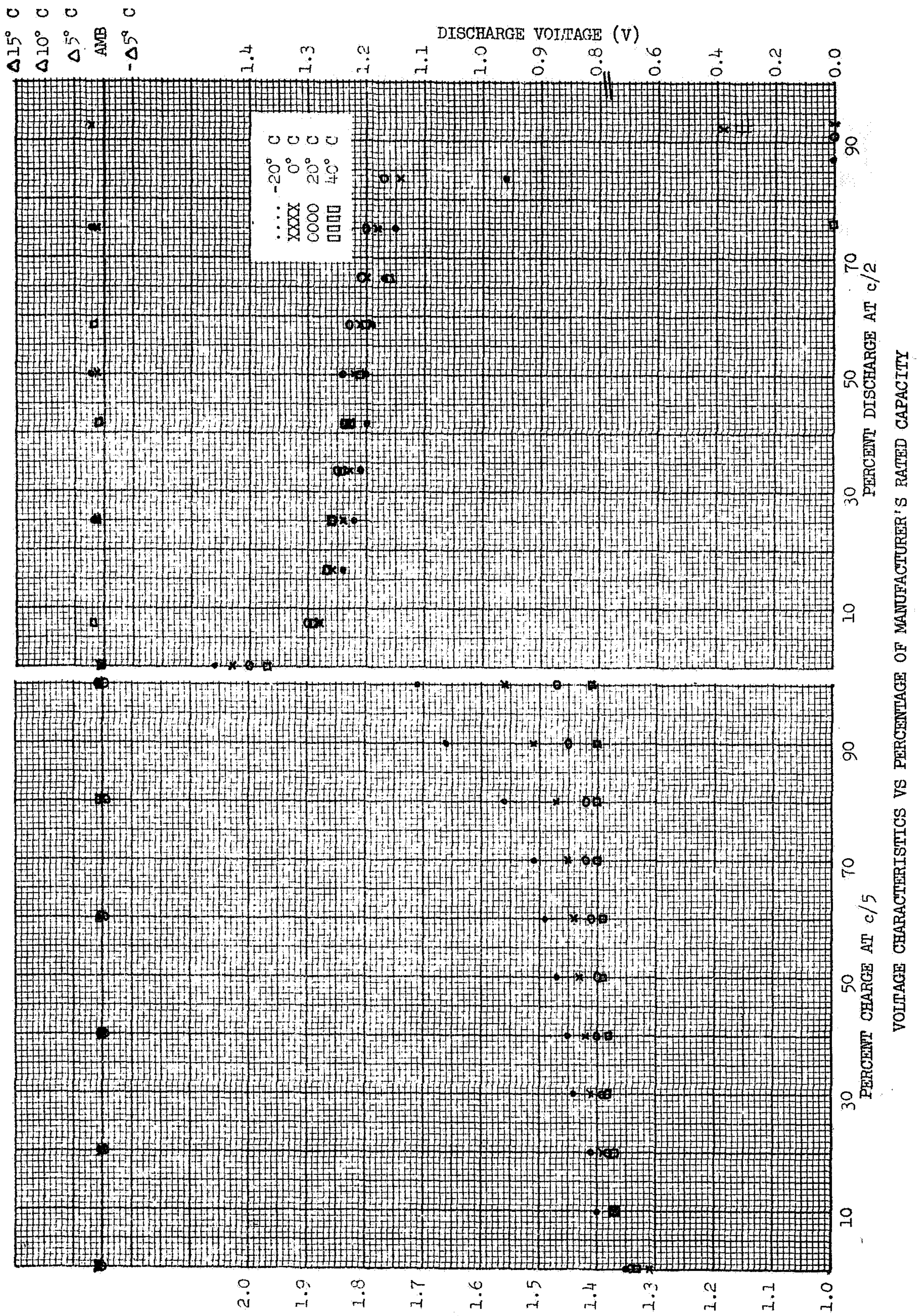
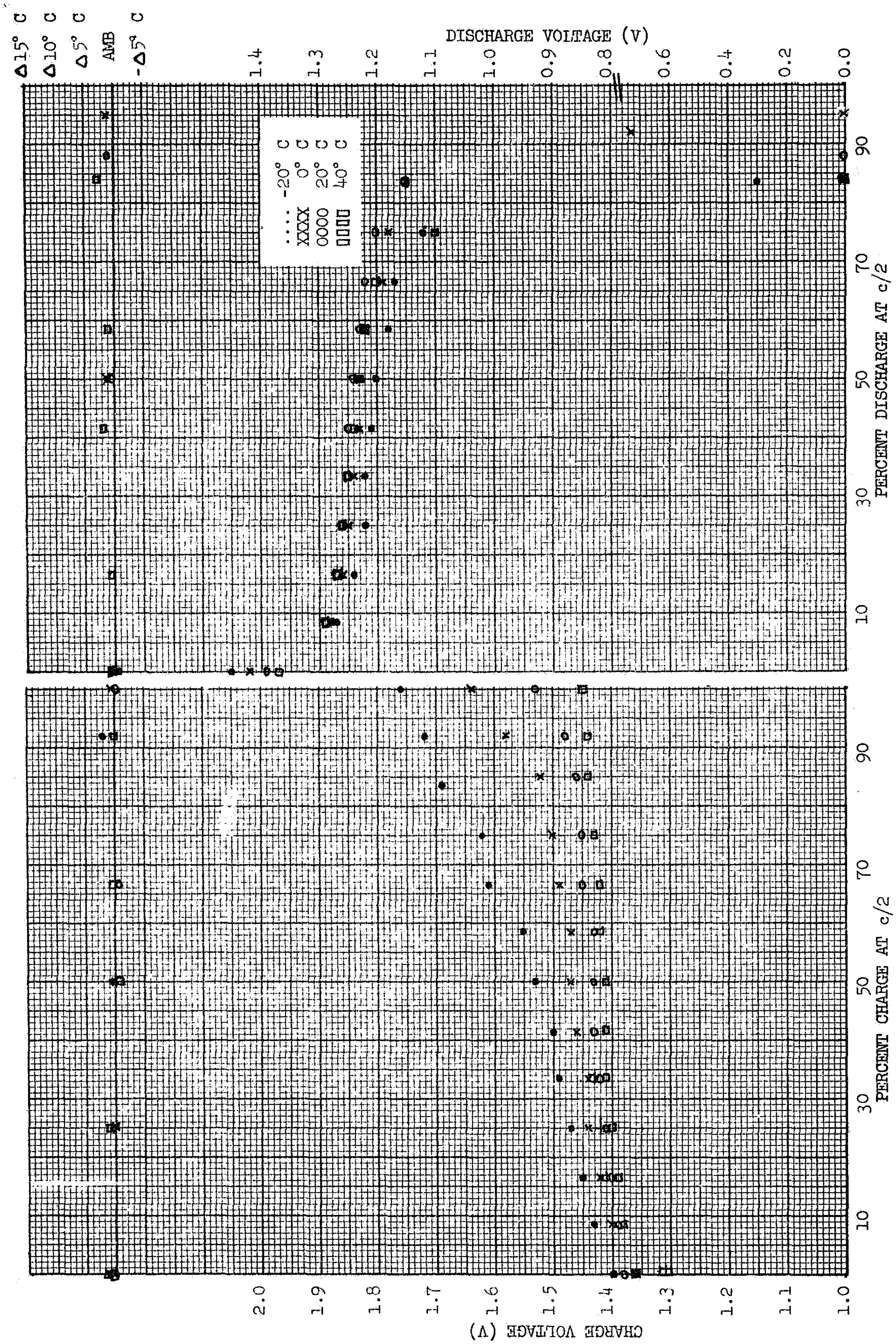
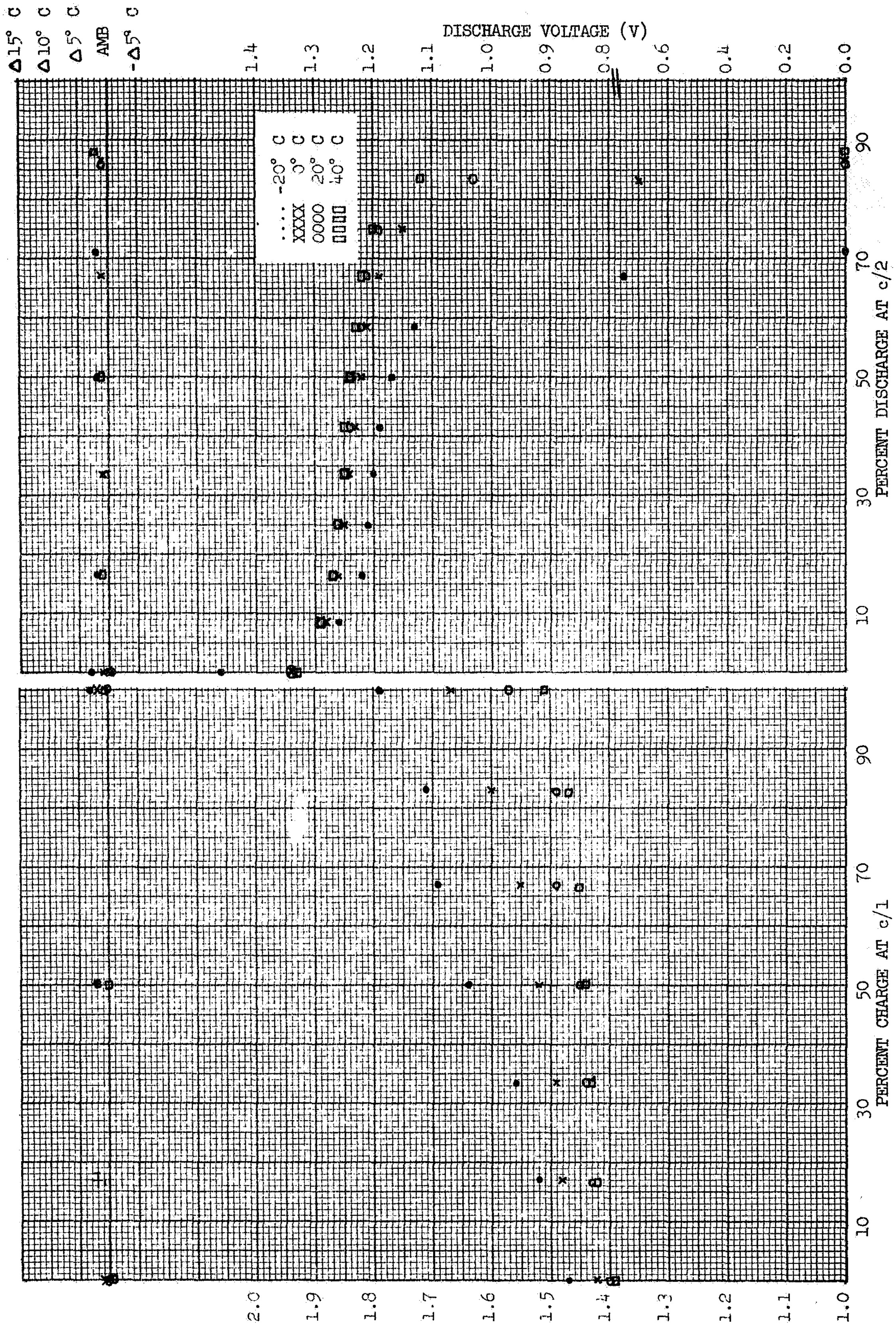

DISCHARGE VOLTAGE (V)
CHARGE VOLTAGE (V)
PERCENT CHARGE AT c/5
PERCENT DISCHARGE AT c/2
VOLTAGE CHARACTERISTICS VS PERCENTAGE OF MANUFACTURER'S RATED CAPACITY
..... -20° C
XXXX 0° C
OOOO 20° C
□□□□ 40° C
Δ15° C
Δ10° C
Δ5° C
AMB
-Δ5° C

FIGURE 4



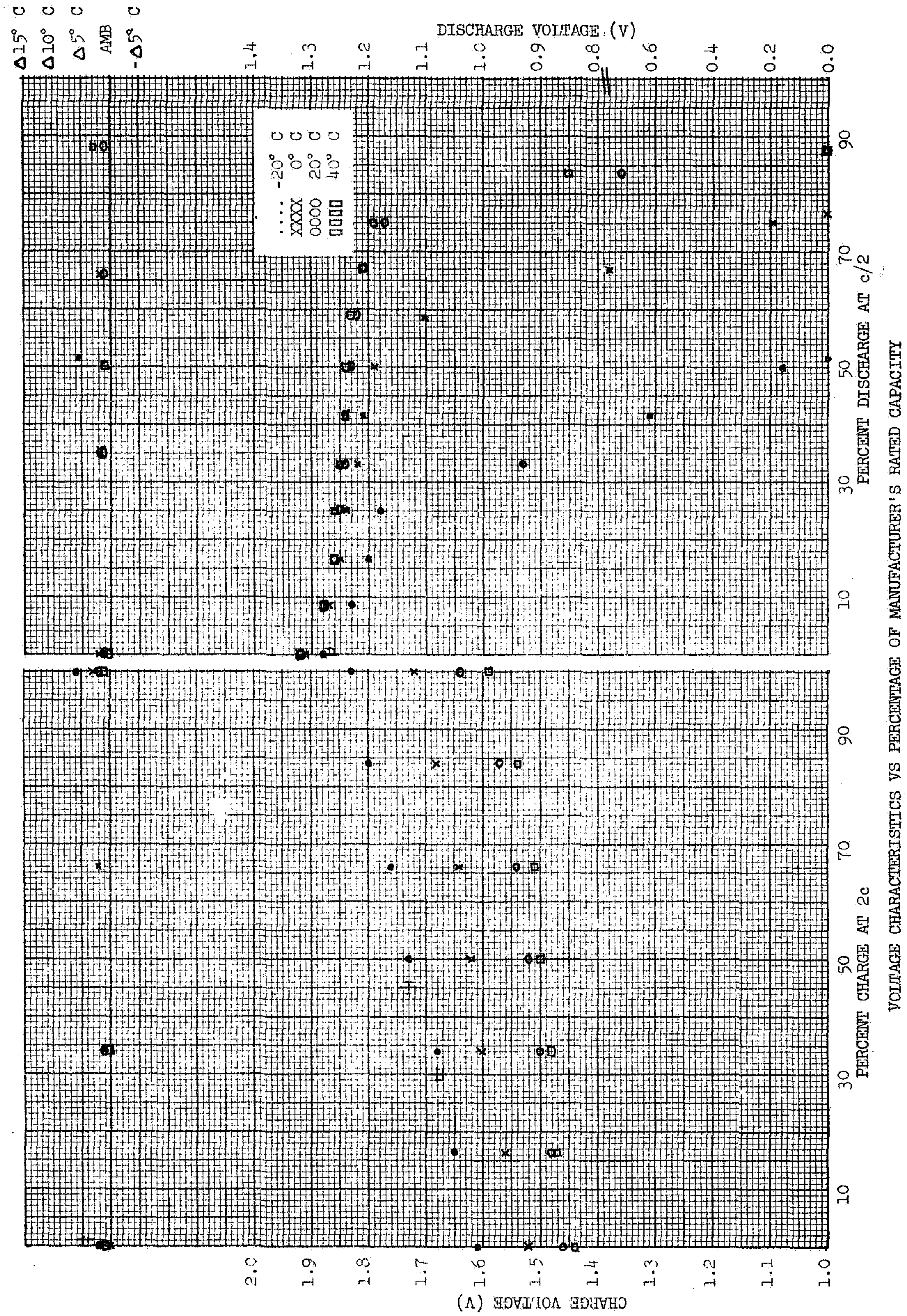
VOLTAGE CHARACTERISTICS VS PERCENTAGE OF MANUFACTURER'S RATED CAPACITY

FIGURE 5



VOLTAGE CHARACTERISTICS VS PERCENTAGE OF MANUFACTURER'S RATED CAPACITY

FIGURE 6



VOLTAGE CHARACTERISTICS VS PERCENTAGE OF MANUFACTURER'S RATED CAPACITY
PERCENT CHARGE AT 2c
PERCENT DISCHARGE AT c/2
CHARGE VOLTAGE (V)
DISCHARGE VOLTAGE (V)
Δ15° C
Δ10° C
Δ5° C
AMB
-Δ5° C
.... -20° C
XXXX 0° C
OOOO 20° C
□□□□ 40° C
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.6
0.4
0.2
0.0
10
30
50
70
90
10
30
50
70
90

FIGURE 7

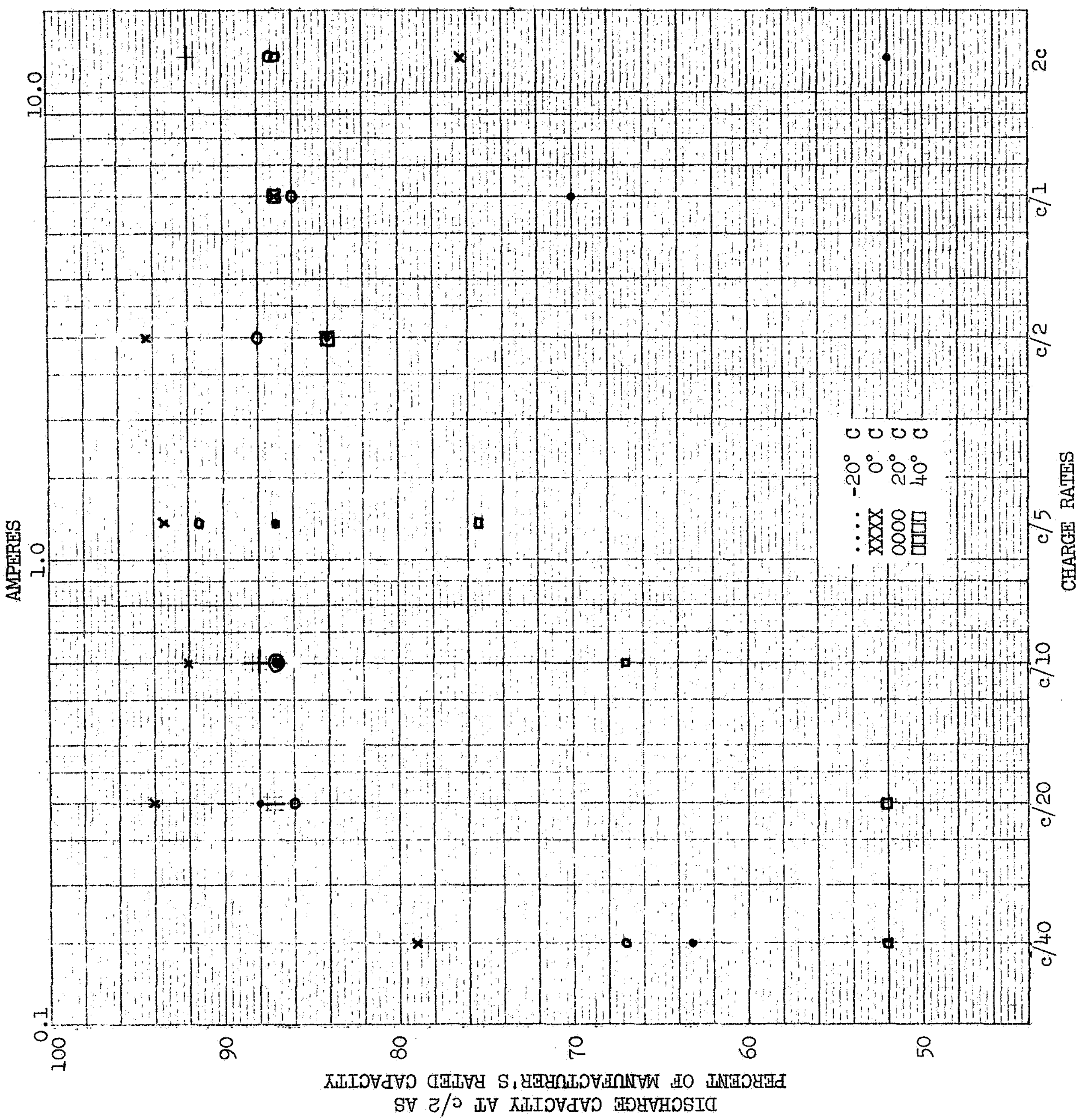
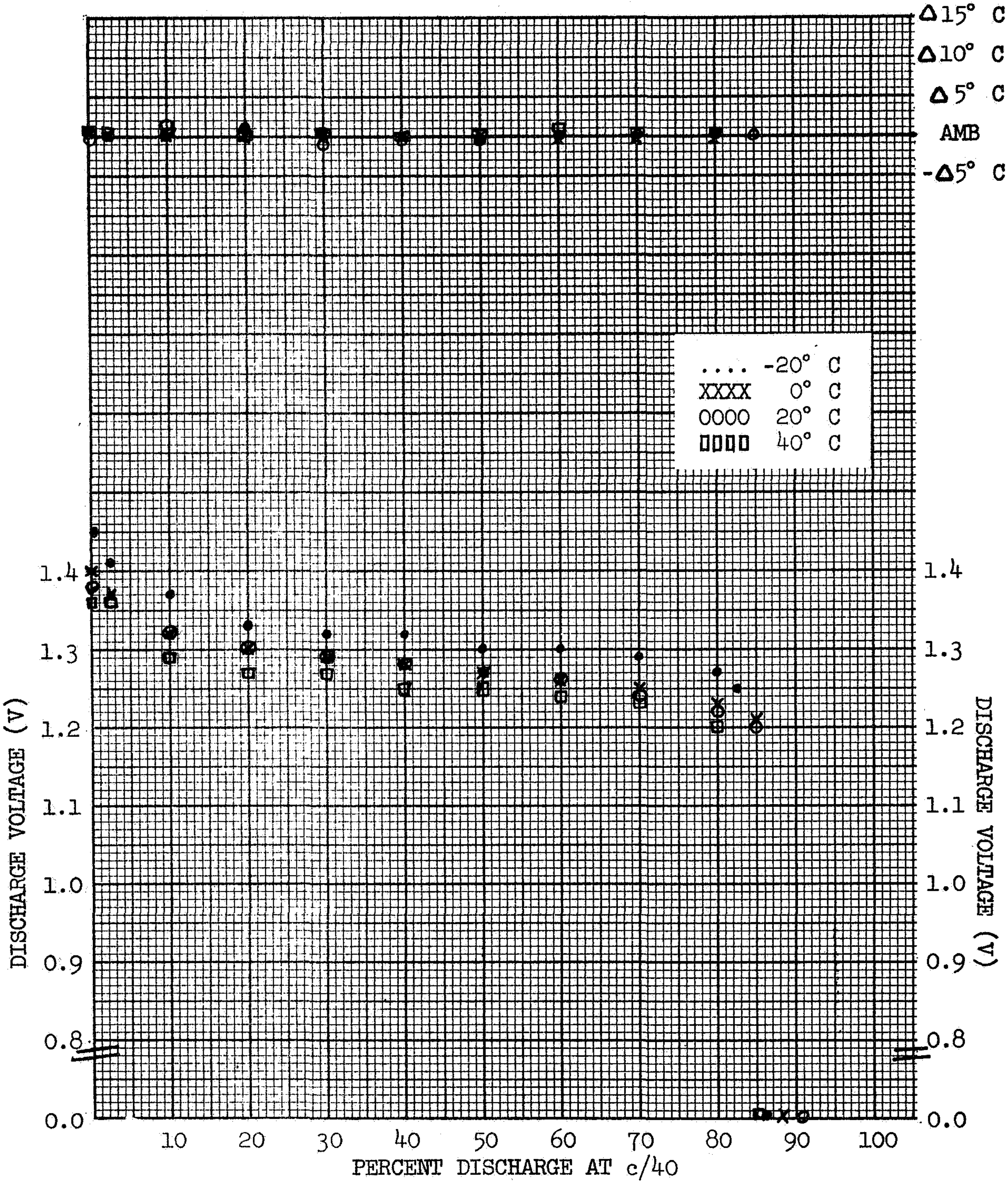
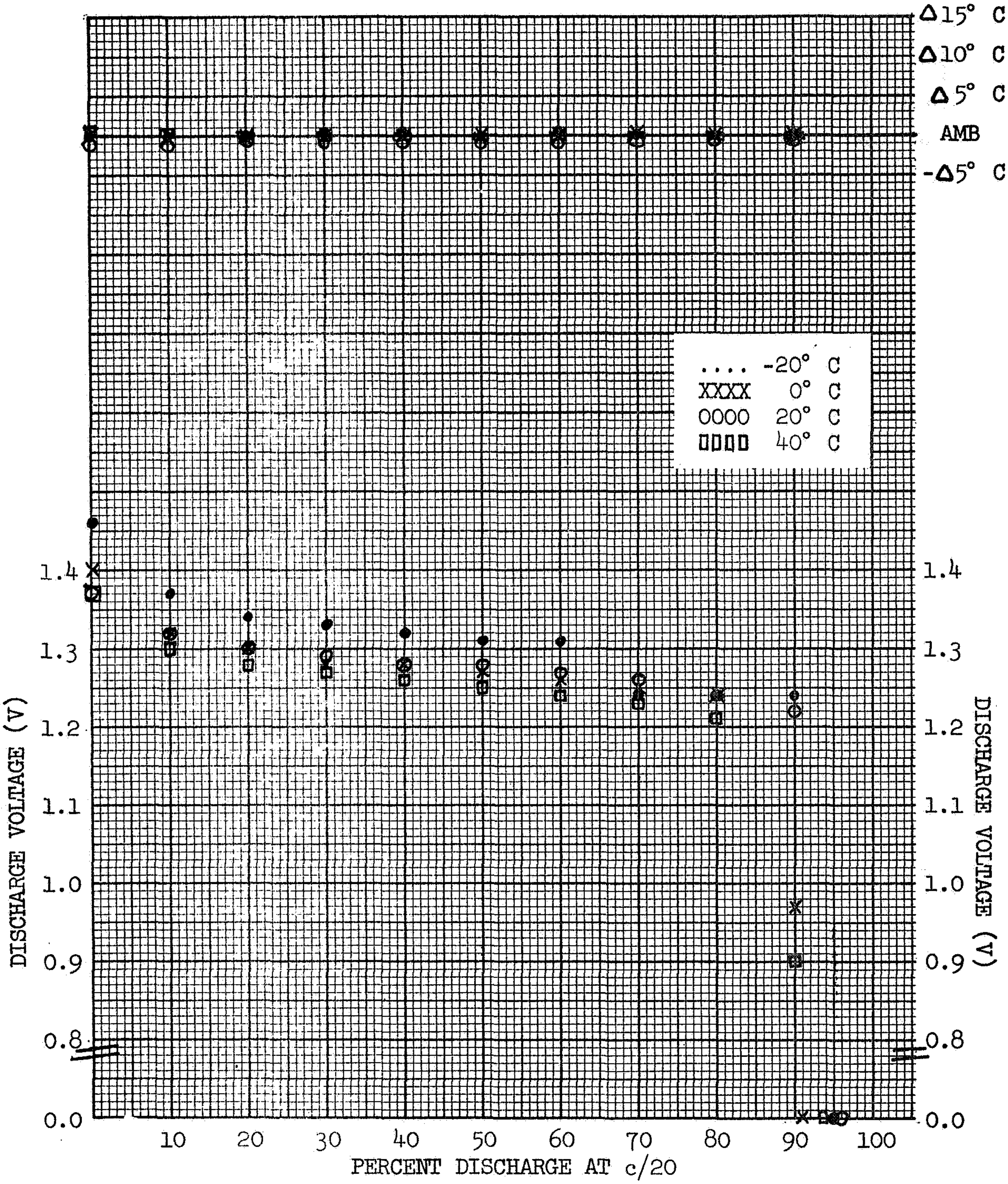

AMPERES
0.1
1.0
10.0
CHARGE RATES
c/40
c/20
c/10
c/5
c/2
c/1
2c
..... -20° C
XXXX 0° C
OOOO 20° C
□□□□ 40° C
100
90
80
70
60
50
DISCHARGE CAPACITY AT c/2 AS
PERCENT OF MANUFACTURER'S RATED CAPACITY

FIGURE 8



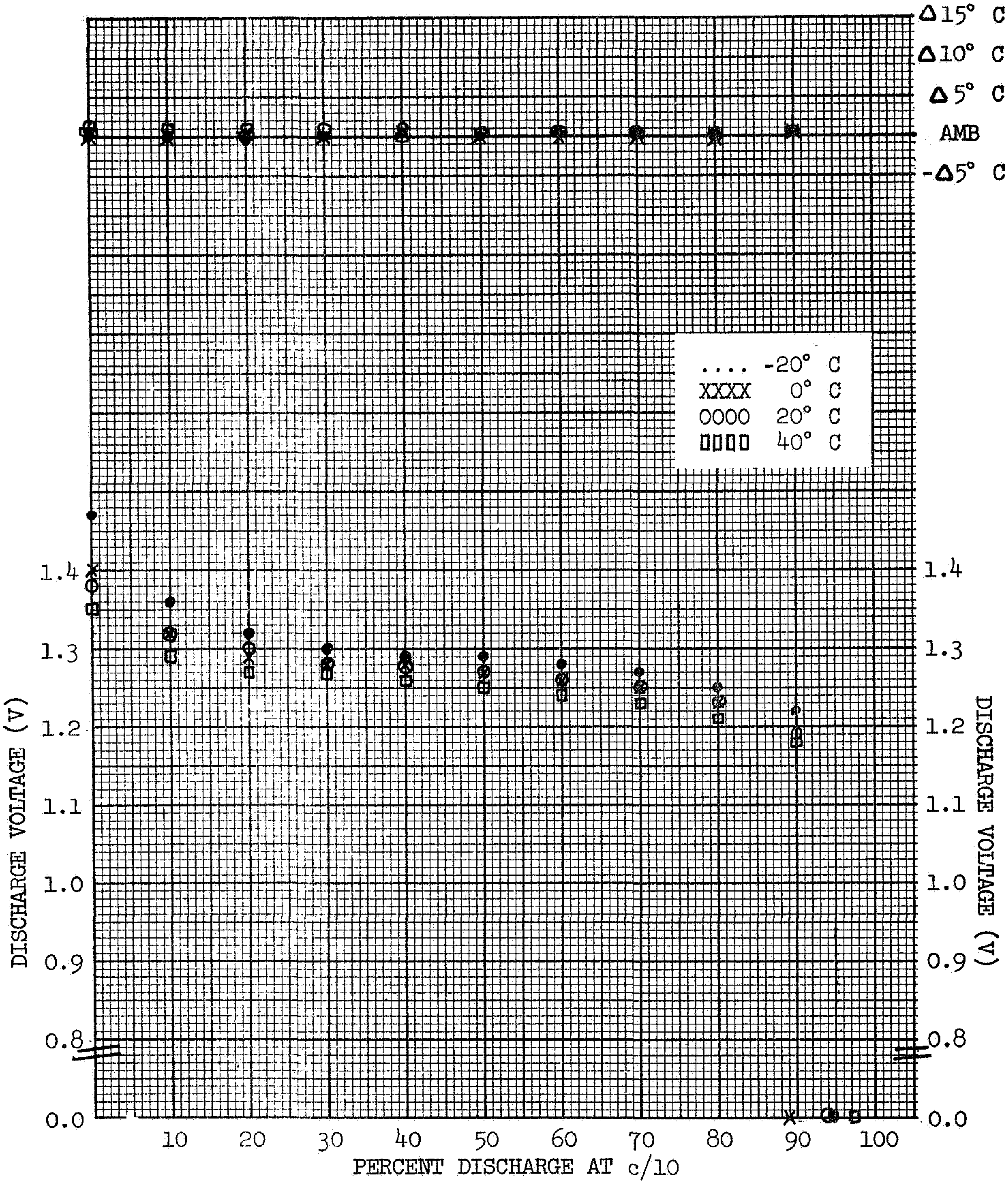
VOLTAGE CHARACTERISTICS VS PERCENTAGE OF MANUFACTURER'S RATED CAPACITY

FIGURE 9



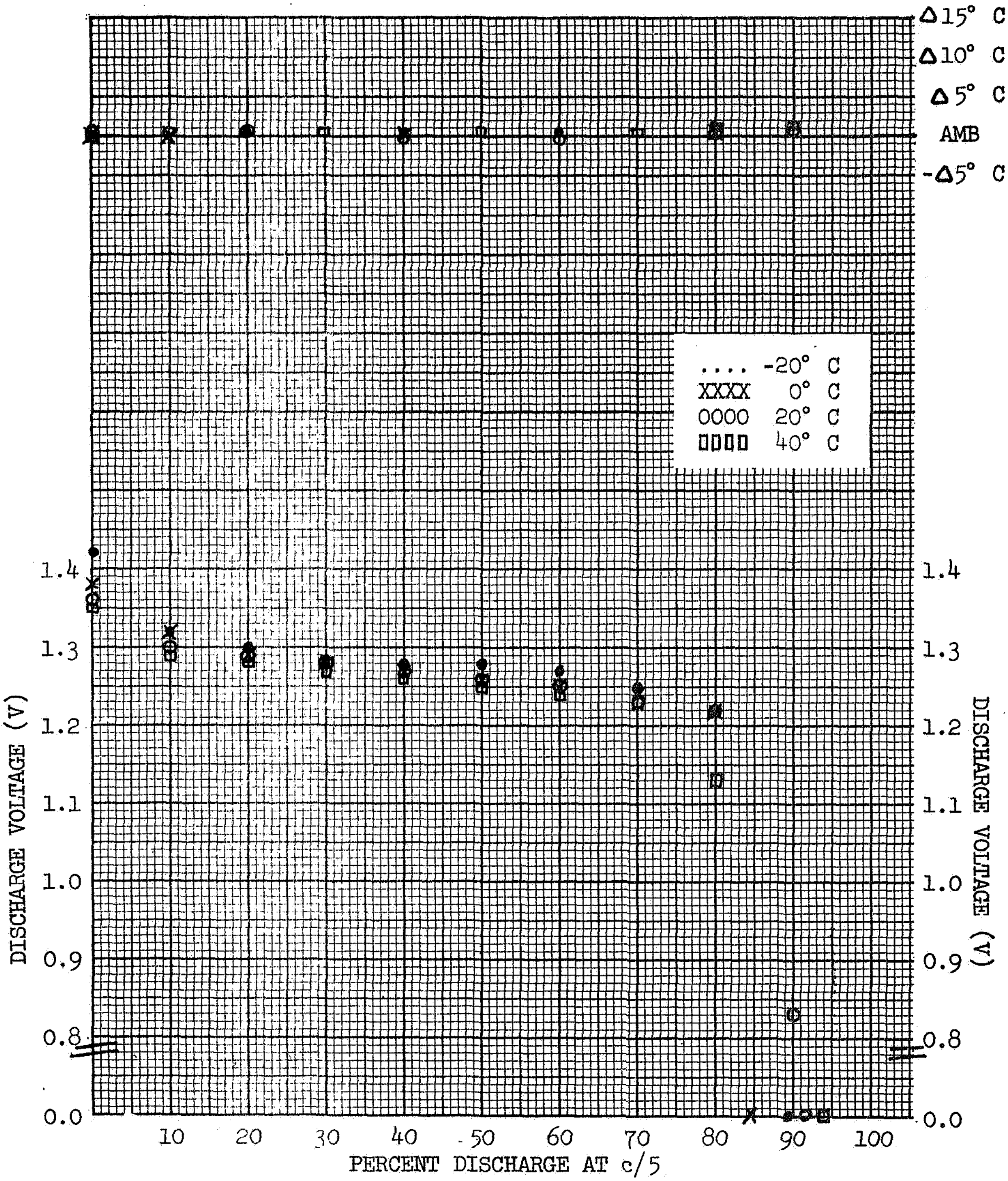
VOLTAGE CHARACTERISTICS VS PERCENTAGE OF MANUFACTURER'S RATED CAPACITY

FIGURE 10



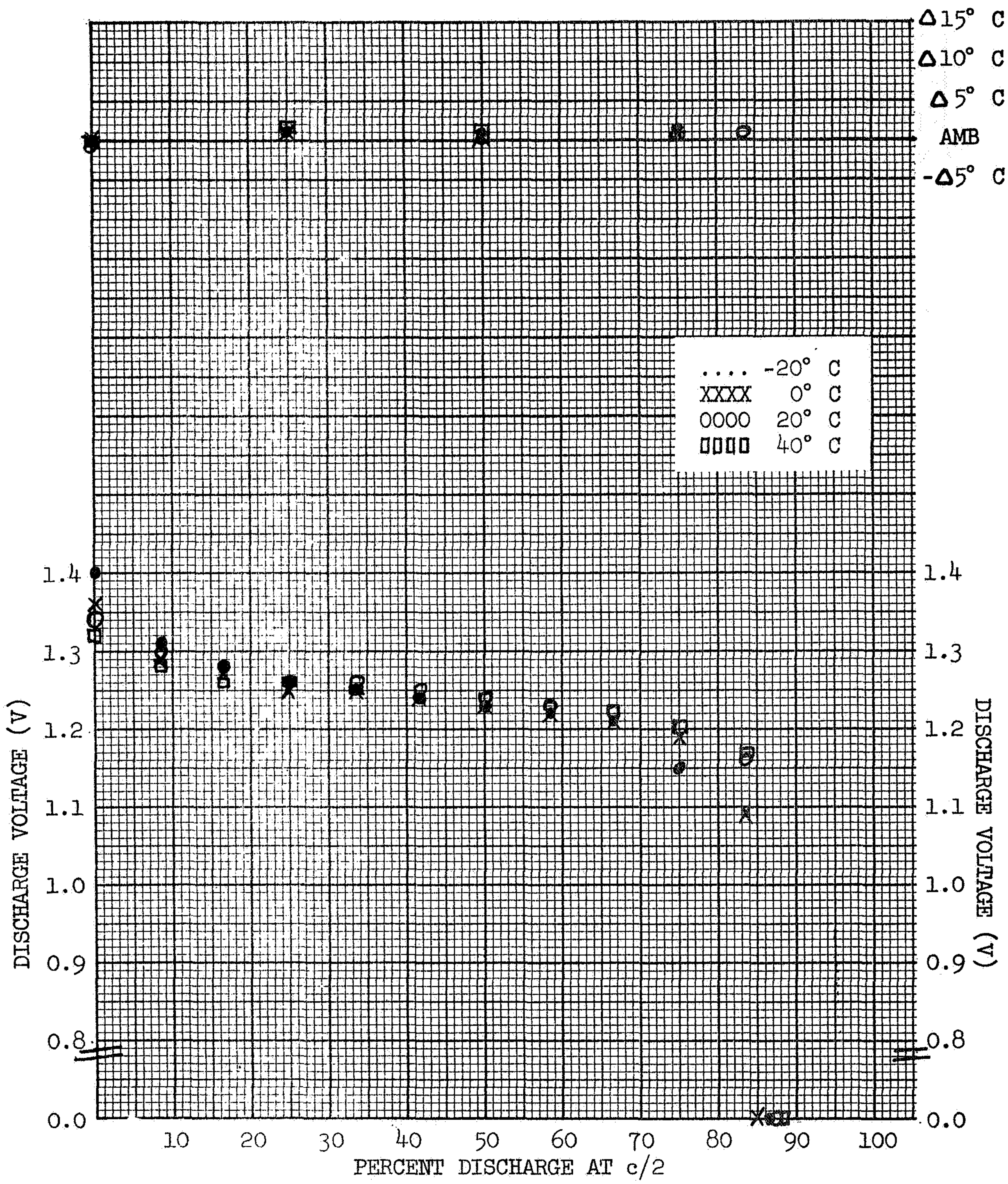
VOLTAGE CHARACTERISTICS VS PERCENTAGE OF MANUFACTURER'S RATED CAPACITY

FIGURE 11



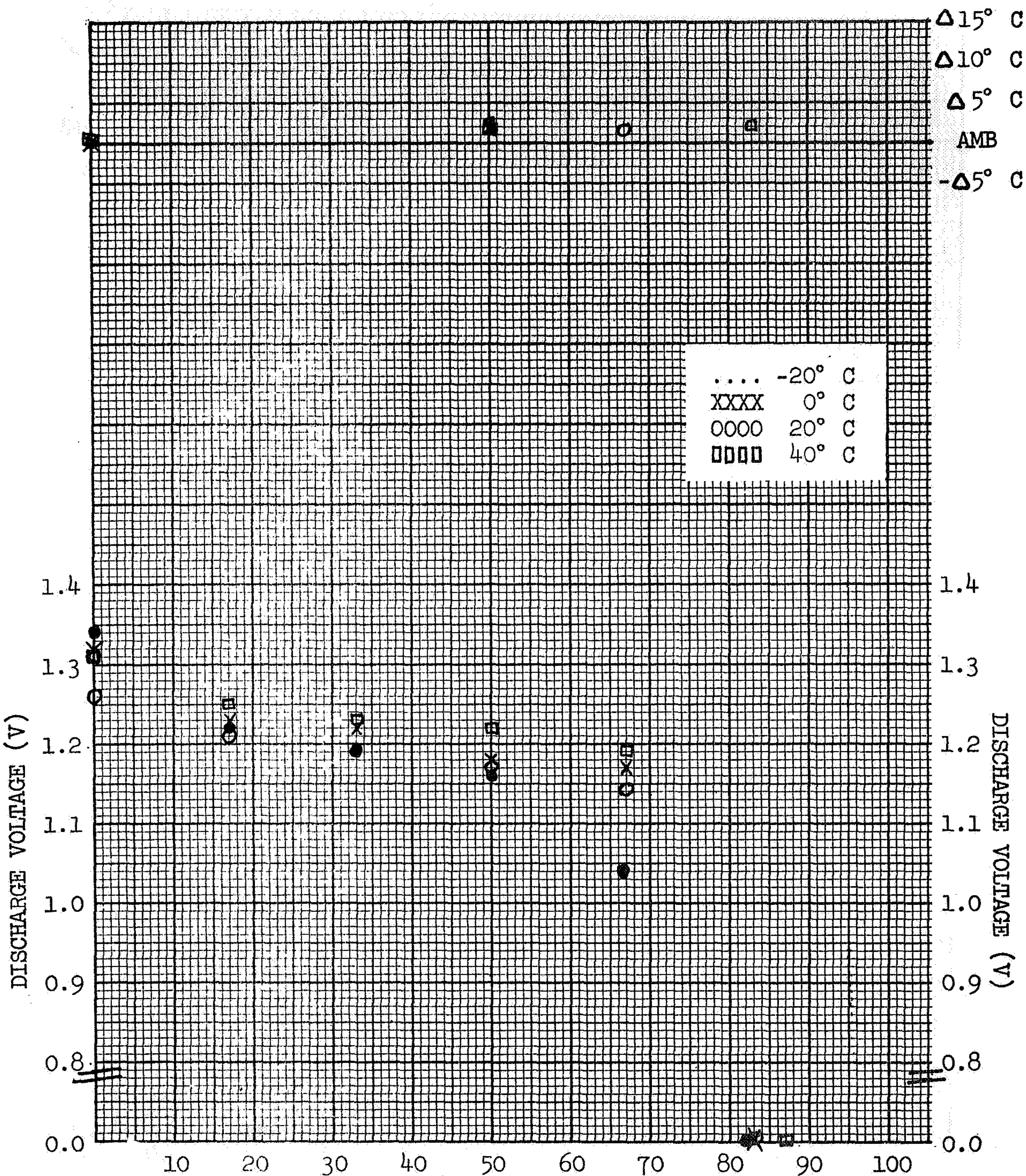
VOLTAGE CHARACTERISTICS VS PERCENTAGE OF MANUFACTURER'S RATED CAPACITY

FIGURE 12



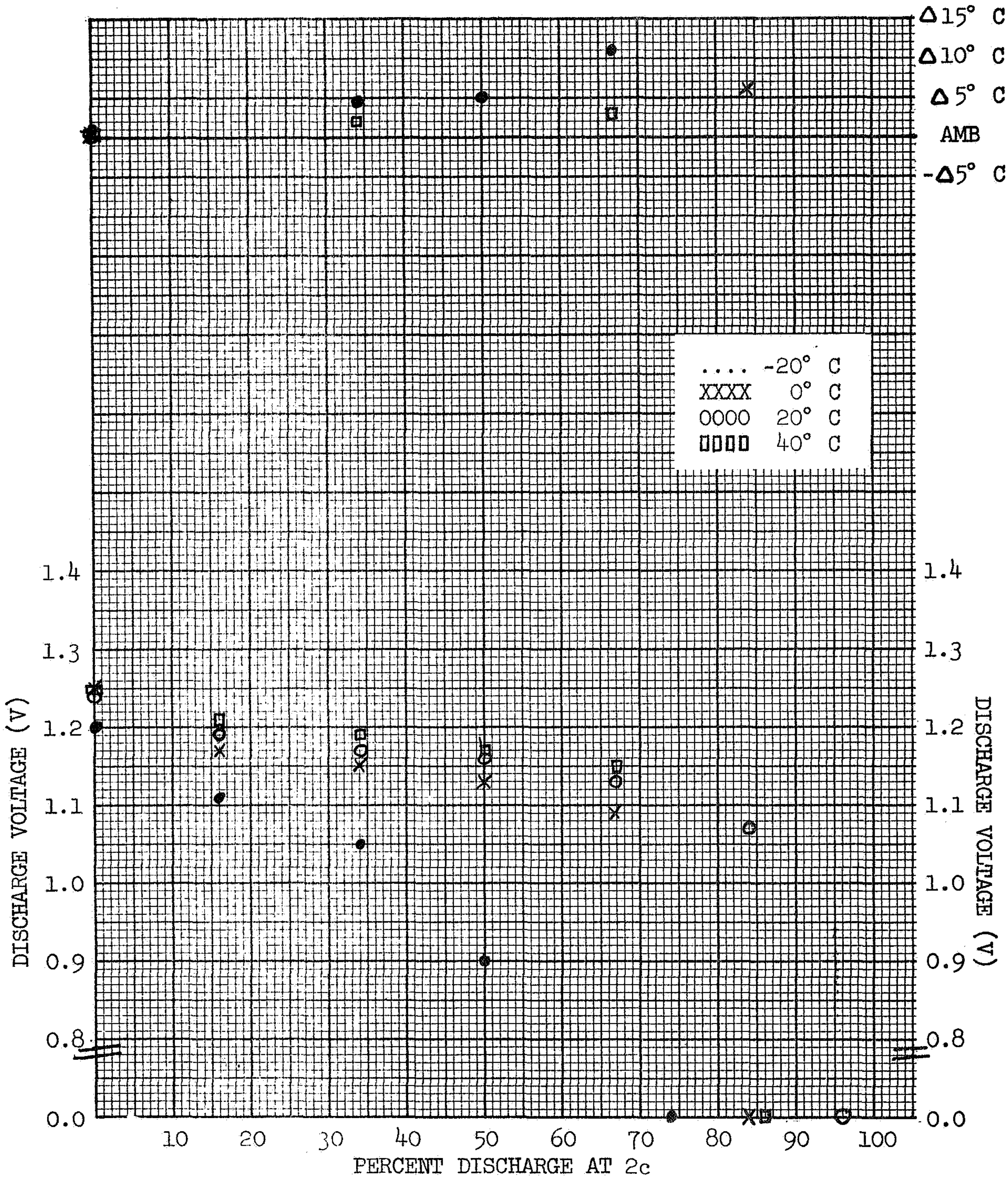
VOLTAGE CHARACTERISTICS VS PERCENTAGE OF MANUFACTURER'S RATED CAPACITY

FIGURE 13



VOLTAGE CHARACTERISTICS VS PERCENTAGE OF MANUFACTURER'S RATED CAPACITY

FIGURE 14



VOLTAGE CHARACTERISTICS VS PERCENTAGE OF MANUFACTURER'S RATED CAPACITY

FIGURE 15

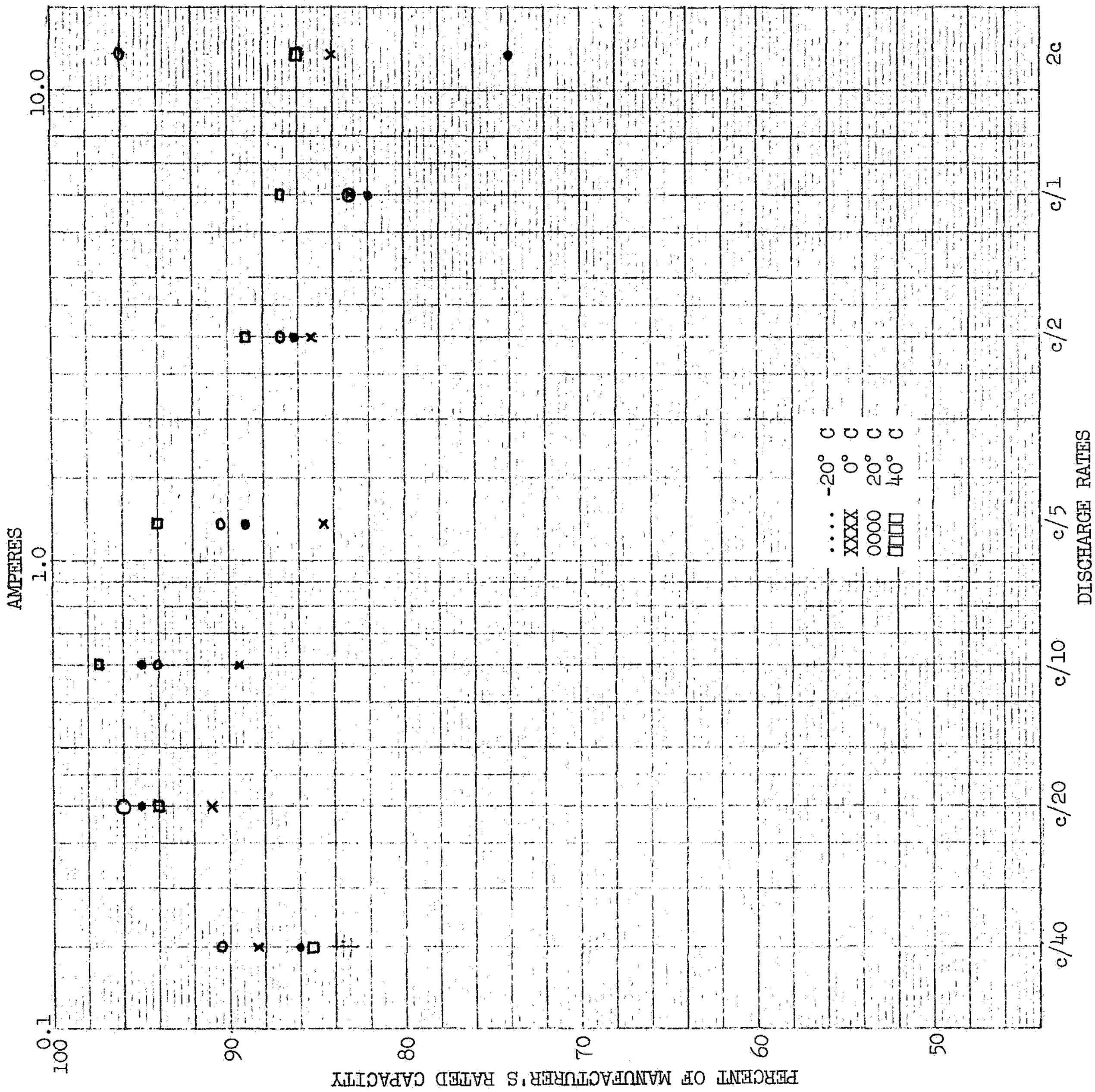

AMPERES
0.1
1.0
10.0
c/40
c/20
c/10
c/5
c/2
c/1
2c
DISCHARGE RATES
100
90
80
70
60
50
PERCENT OF MANUFACTURER'S RATED CAPACITY
..... -20° C
XXXX 0° C
OOOO 20° C
□□□□ 40° C

FIGURE 16

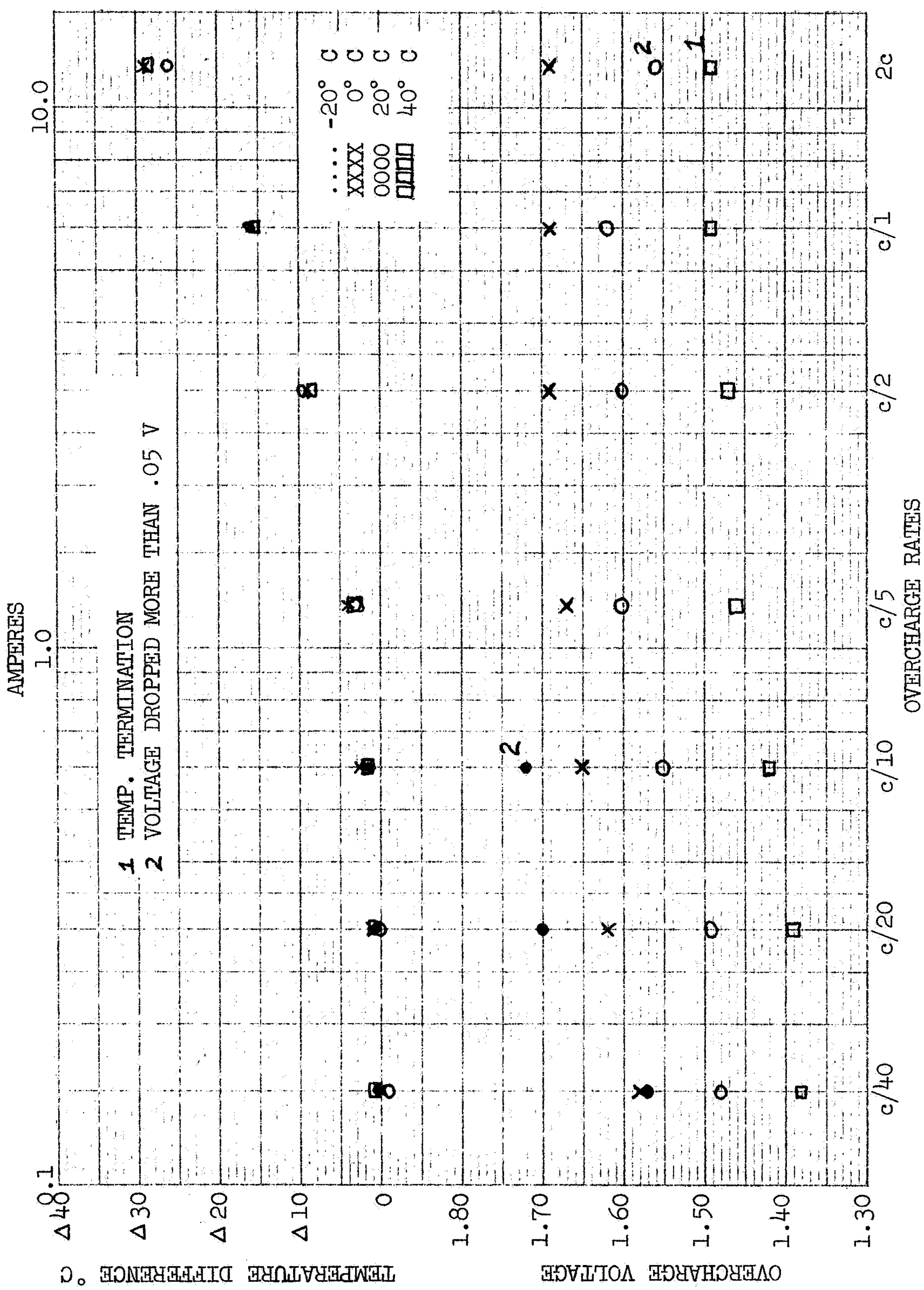

AMPERES
0.1
1.0
10.0
1 TEMP. TERMINATION
2 VOLTAGE DROPPED MORE THAN .05 V
.... -20° C
XXXX 0° C
OOOO 20° C
□□□□ 40° C
TEMPERATURE DIFFERENCE °C
Δ 40
Δ 30
Δ 20
Δ 10
0
OVERCHARGE VOLTAGE
1.80
1.70
1.60
1.50
1.40
1.30
c/40
c/20
c/10
c/5
c/2
c/1
2c
OVERCHARGE RATES

FIGURE 17

DISTRIBUTION LIST

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